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13. ABSTRACT *(Maximum 200 words)*

The genesis of this program lay in the Defense Department recognition that there are first class elements in Russian basic research conducted at many of their premier research institutes. Accordingly, the Defense Department, through the Army Research Office funded the University of Arizona to carry out of campus research in Moscow and St.Petersburg. Key accomplishments are noted in general physics, chemistry, atmospheric research, molicular biology and x-ray imaging.

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INTERACTIONS WITH SURFACES

AND

RELATED STUDIES,

FINAL REPORT

Grant #DAAH04-94-G-0188

By:

The Optical Sciences Center
of the University of Arizona

March 13, 1995

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CHAPTER 1

Brief History. The genesis of this program, in 1992 lay in the Defense Department recognition that there were absolutely first class elements in Russian basic research conducted at many of their premier research institutes. This fact, together with the economic reality of Russian professional salaries being some 50 times less than U.S. counterparts, led to the decision during calendar 1992 to support five specific research programs in Moscow and St. Petersburg, contractually modeled after basic research grants and contracts placed to American universities. Materials, equipment, and operational costs are much the same in Russia as they are in the United States and Europe, so the overall "financial" gain is only about 15 fold over equivalent research being conducted in the United States.

It would have been virtually impossible for any agency within the Department of Defense to directly fund a Russian research institute because the contractual conduit would have been (and probably still would be) through the Russian Academy of Sciences. The ultimate result of this process would be that it would have been fortunate if as much as 10 cents on the dollar were actually deployed by the Russian principle investigators! The "overhead" attached to these funding transfers by the banks, as well as the Academy administration, in series with the Institute front offices themselves, is what accounts for this dreadful loss mechanism.

Accordingly, it was decided that the Defense Department, through the Army Research Office in Raleigh-Durham, would issue a straight-forward grant to the University of Arizona designating Professor Peter Franken as the principle investigator. The University, in turn, would conduct the identified research "off campus" along the established and well audited manner in which off campus research is usually carried out. As examples, we may consider high-energy physicists using accelerator facilities in Geneva, or anthropologists on location

in Peru. For these activities the University takes responsibility for salaries, travel, operational expenses on site, etc. In the present situation, with research being conducted in Moscow and St. Petersburg, the University has again been faced with the task of payroll and other "off campus" expenses, but with somewhat atypical constraints and complications which will be detailed further in this report.

Despite the occasionally bizarre complexities of accomplishing the support of approximately 190 scientists in Russia, this program has been outstandingly successful, as will now be described in the various summaries that follow.

Numerical summary of progress. In the period beginning September 30, 1993 through March 1, 1995 approximately 180 FTE (full time equivalent) Russian Scientists and associated staff have been supported. The research results are diverse, of course, and are summarized in the individual institute reports of chapter 2. The overall publication summary for this ten month period has been as follows:

Number of journal articles published:	56
Number of journal articles accepted for publication:	24
Number of journal articles submitted for publication:	54
Number of journal articles currently in preparation:	19
Number of invited papers presented at conferences, largely international:	23
Number of conference contributed papers:	54

This phenomenal production derives, primarily, from the fact that Russian salaries are much less than their American counterparts, even though operational costs are much the same as in the US. Nevertheless, even with this correction noted, the output has been remarkably high.

Administrative delicacies. Underlying the basic facts of contemporary Russian economics lies the somewhat fundamental fabric of what can be gently described as marginal business practice woven together with corruption. The aphorism "the rich get richer and the poor get poorer" applies to current Russian economics and derives, in large part, from the virtual absence of sensible regulation or controls. The Russian government does not yet understand, seemingly, that "free market economy" has to be exceedingly well (and intelligently) regulated; it is not sufficient just to be free. Accordingly, the University has had to design quite a variety of novel funding mechanisms as well as management procedures to deal effectively with the challenge of this contract.

One of the most vexatious challenges has been establishing an efficient transfer of money to Moscow and St. Petersburg for the monthly payroll journal of some $12,500, as well as an equivalent sum for materials and operations. This money is needed directly in the Russian cities (either in dollars or rubles) and there is no simple or standard procedure for accomplishing such transfers. The familiar mechanism of "wire transfers" from U.S. banks through correspondent institutions in Moscow and St. Petersburg results in losses exceeding 30%. These losses arise from a mixture of excessive banking greed as well as governmental taxation at the Russian end of the transfers, but matters may improve in the near future as (hopefully) Western banks might become licensed to conduct operations in Russia itself. At the present time, of course, many Western banks have offices in Russian cities but are not allowed to conduct conventional cash operations.

The best solution to this dilemma has been for Professor Franken and others to "courier" some of the money on their trips to Russia, supplemented by the use of Western Union (at about a 6% loss) as well as special financial transactions that have been possible from time to time. These are consistently and thoroughly documented with the recognition that they constitute atypical although outstandingly cost effective procedures.

As an interesting example, approximately 50 Russian scientists will have had a visit to the U.S. for the primary purpose of technology transfer, via participation in major U.S. based scientific conferences. Round-trip airfares from Moscow to the east coast run about $600 if purchased on Aeroflot in Moscow but something like $1500 if purchased from Aeroflot in the U.S.A. ! For most of these trips it has been possible for the Russians to scrape together enough cash to buy their tickets in Moscow and, upon presentation of receipts in the United States to be reimbursed in dollars here. This has permitted a substantial savings in travel costs, and is entirely legal within the Russian regulations that currently exist.

CHAPTER 2

Reports of the Individual Institutes. In December 1994, Prof. Franken asked each Principle Investigator in Russia to provide a brief "progress report" to be included in the present document. They were asked to merely describe, briefly, the key accomplishments of their program the previous calendar year. It was emphasized that they should each select material that THEY regarded as important, rather than to anticipate what WE might think was important! In the summaries that follow, the prose of the individual Principal Investigators has been used, with only minor modifications of language made by Professor Franken.

2.1 *The General Physics Institute (Moscow): Alexander Prokhorov, Director and Alexander Nadezhdinskii, Principal Investigator.*

2.1a Key accomplishments.

The accuracy in spectral line intensity measurements was improved significantly based on the identification of the nature of origin of error sources. Accuracy at the level of 0.3% was tested through measurements of water doublet (ortho-, para-modification of water molecule). Accuracy achieved open ability to investigate new orders of perturbation theory in dipole moment presentation.

Pilot instrument to be used in medicine was developed. Surplus content in human respiration of CH_4 equaled ~ 3 - 8 ppm and NH_3 equaled 100 - 250 ppb were detected. The accumulation of CH_4 and NH_3 by human organism seems to be rather negligible for a short time exposure, e.g. like smoking. Data obtained on non invasive CO/CO_2 ratio detection in human breath shows that after 10 - 20 sec of breath holding time the organism's compensation reactions on acute oxygen shortage for breath holding are appeared.

Open path gas analyzer based on tunable diode laser was installed to measure pollutants concentration in automobile exhaust. NO content in a several moving cars was detected. This value was ranged between 100 - 1000 ppm. Theoretical mode without fitted parameters was developed taking into account quantum nature (quasiclassical approach) of translation motion of colliding molecules. Excellent agreement between experiment and calculations observed provides ability to predict collisional cross sections of polyatomic molecules.

Multipass cell with extremely large aperture was developed to be used in diode laser spectroscopy. Pilot sample of diagnostic system based on the multipass cell and near IR diode lasers having sensitivity at 1 - 10 ppm level was manufactured for medical and high technology applications.

TDL based system was adopted to measure pollutant trace concentrations to

automobile exhaust. Test experiments are in progress.

Near IR DL based system was developed to measure parameters of methane high frequency plasma, related to diamond film growth. Several molecules and radicals were detected in the plasma.

Tunable diode laser based analyzer under computer control was developed to measure trace concentration of CO in open atmosphere. The analyzer was installed for nonstop long term CO monitoring.

Pilot instrument to measure trace methane concentration was developed . This instrument is based on Tunable Diode Lasers and multipass cells. The application areas of this instrument are geology, gas industry, detection of gas leakage, etc.

The parameters of impurity absorption bands induced by carbon compounds have been studied in transmission spectra of glasses of the As-S and As-Se systems as well as optical fibers based on these systems. It has been shown that absorption on C-O, C-S, and Cse bonds noticeably affects the transmittance of fibers in mid IR range and carbon is the main limiting impurity for fibers, optical losses being less than 200 dB/km within the wavelength of 5 - 6.5 microns. Our studies provide support for the possibility to produce stable optical fibers using halkogenide glasses of the As-S system, optical losses being about 2.5 (not exceeding 50 dB/km and average strength being about 800 - 1000 Pa).

Experimental specimens of single-mode fibers made of halkogenide glasses of the As-S system obtained and studied for the spectral range of 1.1 - 1.6 microns. Halkogenide glasses with rare earth elements additions such as As_2s_3 with Nd and Ga - Za - S with Pr obtained and studied.

2.1b **Journal articles published.**

1) V. G. Avetisov, A. N. Khusnutdinov, A. I. Nadezhdinskii and M. V. *Zyrianov, Frequency Scale Precision in Diode Laser Spectroscopy,* JQSRT, 49, p. 417-422 (1993).

2) A. Nadezhdinskii, P. Omarova and M. Zyrianov, *Precision limitations of tunable diode laser spectroscopy, in "High Resolution Molecular Spectroscopy,"* A. Nadezhdinskii, Y. Ponomarev and L. Sinitsa, eds. Proc. SPIE, 2205, p. 488- 493 (1994).

3) A. I. Nadezhdinskii, *Spectral Lines Broadening in Polyatomic Molecules Spectra: Local Lines Mixing - in "High Resolution Molecular Spectroscopy,"* A. Nadezhdinskii, Y. Ponomarev and L. Sinitsa, eds. Proc. SPIE, 2205, p. 370-374 (1994).

4) S. M. Chernin, *New Multipass Systems in High Resolution Spectroscopy, - in "High Resolution Molecular Spectroscopy,"* A. Nadezhdinskii, Yu Ponomarev and L. Sinitsa, eds. Proc. SPIE, 2205, p. 523-532 (1994).

5) S. M. Chernin, *New Generation of Multipass Systems, - in "Tunable Diode Laser Spectroscopy,"* A. Fried, D. Killinger and H. Schiff, eds. Proc. SPIE, p. 2112, 99 (1994).

6) S. Kadner, A. Nadezhdinskii and N. Sobolev, *Tunable Diode Laser Spectroscopy: New Methods and Applications, - in "Tunable Diode Laser Spectroscopy,"* A. Fried, D. Killinger and H. Schiff, eds. Proc. SPIE, 2122, p. 45 (1994).

7) E. Desorpere, M. Spiridoo and D. Taebaert, *Diagnostics of Fast-Axial-Flow CO_2 Laser Active Medium Using Diode* Laser Spectroscopy Technique, - in "High Resolution Molecular Spectroscopy," A Nadezhdinskii, Yu Ponomarev and L. Sinitsa, eds. Proc. SPIE, 2205, p. 435-439 (1994).

8) E. Desoppere, C. Leys, S. McKenna-Lawlor, S. Sazhin, M. Spiridonov, D. Toebaert and P. Wild, *Investigation of the Active Medium of a Direct-Current-Excited Fast-Axial-Flow CO_2 Laser Using a Tunable Diode Laser, -* J. Phys. D, 27, p. 962-969 (1994).

9) S. Chernin, *Multimirror Scanning Spectropyrometer,* - J. of Modern Optics, 41, p. 471- 479 (1994).

10) I. A. Adamovskaya, S. McKenna-Lawlor, K. L. Moskalenko, A. I. Nadezhdinskii, N. V. Sobolev and E. V. Spepanov, *Tunable diode laser application for fully automated absolute measurements of CO and CO_2 concentration in human breath, - in "High Resolution Molecular Spectroscopy,"* A. Nadezhdinskii, Yu Ponomarev and L. Sinitsa, eds. Proc. SPIE, 2205, p. 440-447 (1994).

11) K. L. Moskalenko, A. I. Nadezhdinskii and E. V. Spepanov, *Tunable diode laser spectroscopy application for ammonia and methane content measurements in human breath, - in "High Resolution Molecular Spectroscopy,"* A. Nadezhdinskii, Yu Ponomarev and L. Sinitsa, eds. Prod. SPIE, 2205, p. 448-452 (1994).

2.1c **Journal articles accepted.**

1) A. I. Nadezhdinskii and P. M. Omarova, *Precision limitations of diode laser spectroscopy: spectral line shape measurements: baseline consideration,* JMS (1994).

2) A. Nadezhdinskii, *New generation of tunable diode laser based systems,* Infrared Physics & Technology.

3) S. McKenna-Lawlor, S. Y. Savinov and M. V. Spiridonov, *Diagnostics of the active medium of a waveguide CO_2 laser: vibrational distributions and plasma-chemical process,* Journal of Quantitative Spectroscopy and Radiative Transfer.

2.1d **Journal articles submitted for publication.**

1) A. I. Nadezhdinski, *Diode laser spectroscopy: Precise spectral line shape*

measurement, Spectrochimica Acta Review.

2) F. D. Amato, G. Baldacchini, M. DeRosa, N. Lemekhov, A. I. Nadezhdinskii and N. Obolev, *Measurement of Atmospheric CO concentration with tunable diode lasers*, Infrared Physics & Technology.

3) I. A. Adamovskaya, K. L. Moskalenko and A. I. Nadezhdinskii, *Human breath trace gas content study by tunable diode laser spectroscopy technique*, Infrared Physics & Technology.

4) E. Desorpere, C. Leys, M. Spiridonov and D. Toebaert, *TDL diagnostics of a fast-axial-flow CO_2 laser active medium: vibrational distributions and plasma-chemical reactions*, Infrared Physics & Technology.

2.1e **Journal articles currently in preparation.**

1) G. Balducchini, A. Bellatreccia, A. Ciucci, F. D'Amato, N. Lemekhov, A. Nadezhdinskii, and N. Sobolev, *Misura Della Concentracione del CO Nell'Atmosfera con Diodi Laser Sintonizzibili.*

2) M. Kerimkulov, A. Nadezhdinskii, S. Savinov, M. Spiridonov and Y. Zadorozhny, *Near IR TDL spectroscopy of a glow discharge hydro-carbon plasma.*

2.1f **Invited papers presented at conferences.**

1) A. Nadezhdinskii, *Tunable Diode Laser Spectroscopy: New Methods and Applications*, Symposium on Optical Sensing for Environment Monitoring, (Oct. 1993) Atlanta, Georgia.

2) K. Moskalenko, *Human Breath Trace Gas Content Study by Tunable Diode Laser Spectroscopy Technique*, - 4th International Symposium on Monitoring of Gaseous Pollutants by Tunable Diode Lasers, 19 - 20 October, 1994, Freiburg, Germany.

2.1g **Contributed papers presented at conferences.**

1) 3 Covegno Nazionale *"Strumentazione e Metodi di Misura Elettroopttici,"* (March 1994) Pavia, Italy (1 paper).

2) *Symposium on Optical Sensing for Environment Monitoring,* (Oct. 1993) Atlanta, Georgia (3 papers).

3) *4th International Symposium on Monitoring of Gaseous Pollutants by Tunable Diode Lasers,* (Oct. 1994) Freiburg, Germany (4 papers).

4) *SPIE's International Symposium on Optics, Imaging, and Instrumentation,* (July 1994) San Diego, California, exhibition participation (3 instruments).

5) *9th International Symposium on Non-Oxide Glasses (Halide Glasses),* (May 1994) Hangzhou, China (2 papers).

2.2 *The Ioffe Physico-Technical Institute (St. Petersburg); Zhores Alferov, Director and Valentine Chelnokhov, Principal Investigator.*

2.2a **Key accomplishments.**

During this year, we have continued research on single crystalline silicon carbide and devices on its base; amorphous materials such as carbon, silicon carbide and diamond-like materials. Also, we have started investigations on porous silicon carbide and ferroelectric materials deposited onto single crystalline silicon carbide.

The most part of work on the project for 1994 was devoted to the research of single crystal silicon carbide. The results obtained are reflected in 10 papers contributed at International Conferences and in 32 journal papers, i.e.. approximately 2/3 from whole number of publications. Besides, these results are also presented in two large Research Activity Reports (see Appendix 3.) Growth of single crystal silicon carbide is described in conference papers [1,7] and in journal papers [SiC: 2, 3, 11, 14, 16, 18, 31 and 32.]

Fundamental properties of silicon carbide have been studied in journal papers [SiC: 4-9, 17, 19, 20 and 22-30.] Developments of different devices on the base of silicon carbide are presented in conference papers [3, 5, 6 and 8-12] and in journal papers [SiC: 1, 10, 12, 13, 15, 21 and 32.]

We have succeeded in fabricating single crystal boules of 6H-SiC and 4H-SiC (1 inch diameter) by modified sublimation growth; homo- and hetero-structures have been sublimation "sandwich" -method, with improved quality.

With the creation CVD setup, we have carried out successful experiments on CVD homo-epitaxial growth of 6H-silicon carbide films in the system CH_3SICI_3-hydrogen. Our purpose for the near feature is growing films with a small amount of contaminations and to perform controlled doping. We have to declare that we are behind the West in CVD growth because we have no possibility now to buy very expensive equipment.

One of the most promising properties of silicon carbide is that silicon carbide can be oxidized with silicon dioxide formation at the surface. Such a property allows fabrication planar devices like silicon MOS devices with creating high temperature radiation hardened integrated circuits. However, there is a need to do a lot of work in order to improve the SiO_2/SiC interface that plays the key role in MOS device operation. We were the first who studied the interface SiO_2/SiC at temperatures as high as 300° C. In particular, we have determined parameters of deep level interface traps. Partly, referring to our results, Pr. Brown from General Electric explained at the 2nd HiTEC some features of MOSFETs behavior at elevated temperatures.

Among other works on monocrystalline silicon carbide, we would like to notice the work on producing silicon carbide combined transistor processing buried-gate JFET, MESFET and Shottky collector BT in one of the same structures

We have obtained porous silicon carbide featuring the intensity of the photo-luminescence 15-20 times higher as compared to the initial monocrystalline material.

Finally, we would like to note the work on the study of ferroelectric films deposited

onto monocrystalline silicon carbide. Being radiation hardened together with silicon carbide, ferroelectric films deposited onto silicon carbide are a promising structure for production radiation resistant, high temperature operation memory cells. By now, we have obtained ferroelectric - silicon carbide MfeS capacitors showing a hysteresis in electric polarization of ferroelectric film.

To deposit amorphous materials, two techniques are available in our laboratory:

1) magnetron assisted gas decomposition (MAGD) and,

2) plasma assisted chemical vapor deposition.

There are 5 papers devoted to amorphous films of $Si_{1-x}C_x$:H and C:H [Amorphous wide bandgap materials: 1-5] and 2 papers devoted to amorphous films of AIN [Amorphous wide bandgap materials: 6,7.] Research has been carried out on both fundamental properties of these materials (we would like to notice the pioneer work on Raman study of amorphous hydrogenated silicon carbide material) and device technology.

There is a growing interest around the world to both carbon and diamond like films. We are conducting new fundamental investigations of such films obtained via plasma assisted chemical deposition technique (see conference papers [2-4] and journal papers [Carbon and diamond-like films 1-13].)

In this field of research, the most interesting work was to explain the nature of superconductivity in the system fulleren: copper. We have investigated the changes in X-ray spectra of the fulleren: copper mixture subjected to thermal anneal at different temperatures. We have succeeded in observation at least three chemical compounds between carbon and copper unknown by the day. The ratio found to depend on anneal temperature. Having reviewed the spectra evolution, we have put an assumption in regards to that phase that is responsible for the superconductivity.

In conclusion, we would like to declare that we have conducted research on all items of the '94 project. We consider our results obtained to be effective. From our point of view, an advance has been achieved in technologies of silicon carbide and related materials.

2.2b **Journal articles published.**

1) M. M. Anikin, V. E. Chelnokov, A. A. Lebedev, M. G. Rastegaeva, N. S. Savkina, A. M. Strel'chuk and A. L. Syrkin, *SiC FET with low threshold voltage*, Pis'ma v Zh. Tech. Fiz., Vol. 20, No. 10, p. 6-19 (1994).

2) M. M. Anikin, V. E. Chelnokov and A. L. Syrkin, *Outlook for the development of sublimation epitaxy of silicon carbide, Semiconductors*, Vol. 27, No. 7, p. 700-701 (1994).

3) M. M. Anikin, V. E. Chelnokov, A. A. Lebedev, M. G. Rastegaeva, A. M. Strel'chuk and A. L. Syrkin, *Epitaxial films and pn-junctions grown by a sublimation method in a system with electrin heating*, Semiconductors, Vol. 27, No. 7, p. 702-703 (1994).

4) V. E. Chelnokov, A. M. Danishevsky and A. Y. Rogachev, *Surface ultraviolet photoluminescence in SiC*, Fizika i Technika Poluprov (1994, No.9).

5) V. E. Chelnokov, P. A. Ivanov, V. N. Panteleev and T. P. Samsonova, *Investigation of surface states at the SiO_2-SiC interface by means of analysis of input admittance of MOS-structure in a wide temperature range*, Fizika i Technika Poluprov (1995, N2).

2.2c **Journal articles accepted for publication.**

1) A. N. Andreev, M. M. Anikin, V. E. Chelnokov, V. V. Zelenin, P. A. Ivanov, A. A. Lebedev, M. G. Rastegaeva, N. S. Savkina, A. L. Syrkin and A. M. Strel'chuk, *High Temperature Silicon Carbide Stabilitrons for the Voltage Range from 4V to 50V*, Proc. of E-MRS 1994 Spring Meeting (Symposium E: High Temperature Electronics: Materials, Devices and Applications) Strasbourg, France (May 1994).

2) A. N. Andreev, V. E. Chelnokov, A. A. Lebedev, M. G. Rastegaeva and A.

L. Syrkin, *Surface Barrier Height in Metal-n-6H-SiC Structures*, Proc. of E-MRS 1994 Spring Meeting (Symposium E: High Temperature Electronics: Materials, Devices and Applications), Strasbourg, France (May 1994).

3) A. N. Andreev, V. E. Chelnokov, A. M. Strel'chuk, N. S. Savkina and F. M. Snegov, *High Temperature SiC-6H Dinistor*, Proc. of E-MRS 1994 Spring Meeting (Symposium E: High Temperature Electronics: Materials, Devices and Applications), Strasbourg, France (May 1994).

4) M. M. Anikin, V. E. Chelnokov, A. A. Lebedev, M. G. Rastegaeva, N. S. Savkina, A. L. Syrkin, A. M. Strel'chuk and S. Tyc, *High Temperature Silicon Carbide Combined Transistor*, Proc. of E-MRS 1994 Spring Meeting (Symposium E: High Temperature Electronics: Materials, Devices and Applications) Strasbourg, France (May 1994).

5) V. Chelnokov and V. Dmitriev, *Wide Bandgap Electronic Devices*, Proc. of ISDF2 and NATO Advanced Work Shop on Wide Bandgap Electronic Materials, Minsk, Belarus (May 1994).

6) V. E. Chelnokov, P. A. Ivanov, G. Lentz, C. Parniere and A. M. Strel'chuk, P *Silicon Carbide p-n Structures as Power Rectifiers*, Proc. of ISPSD94, Davos, Switzerland (May 31-June 2, 1994).

7) V. E. Chelnokov, P. A. Ivanov, V. N. Panteleev and T. P. Samsonova, *Investigation of surface states at the SiO_2-SiC interface by means of analysis of input admittance of MOS-structure in a wide temperature range*, Fizika i Technika Poluprov, (1995, N2).

8) O. I. Konkov, E. I. Terukov and I. N. Trapeznikova, *Electron Mobility and Density of States in a-C:H*, Semiconductors, v.28, N8, p.1406-1410 (1994).

9) O. I. Konkov, E. I. Terukov, I. N. Trapeznikova and S. G. Yastrebov, *Modification of a-$Si_{1-x}C_x$:H films properties by high temperature annealing*, Solid State Physics, v. 36, N9, p.2780-2784 (1994).

10) T. A. Antonova, I. M. Kotina,, G. V. Patsekina, V. D. Saveliev and L. M. Tuhkonen, *Application of Amorphous Hydrogenated Carbon Coating to Semiconductor Radiation Detectors*, Proc. of ISDF2 and NATO Advanced Work Shop on Wide Bandgap Electronic Materials, Minsk, Belarus (May 1994).

11) N. V. Elkina, R. A. Kavalauskas, V. K. Kudoyarova, E. I. Terukov, I. N. Trapeznicova and G. N. Violina, *Optical and Electrical Properties of a-$Si_{1-x}C_x$:H Layers That Can Fined Application in Electro-Photography*, Fizika i Technika Poluprovodnikov, v. 21, N8, p.1310-1321 (1994).

12) M. M. Anikin, V. E. Chelnokov, A. A. Lebedev, , M. G. Rastegaeva, N. S. Savkina, and A. M. Strel'chuk, *Electrophysical Properties and Device Application of the SiC Thin Films*, "Thin Films" ed. by G. Necht, F. Richer, and J. Hahm (Proc. of the joint TATF94 and HVITF94, Dresden, Germany, (March 1994).

13) V. E. Chelnokov, A. N. Kuznetsov, N. A. Rogachev, I. N. Trapeznikova and E. I. Terukov, *Amorphous Hydrogenated Silicon Carbide Obtained by Magnetron Reactive Sputtering*, Semiconductors, v. 28, N8, p.1375-1381 (1994).

2.2d **Journal articles submitted for publication.**

1) A. N. Andreev, A. I. Babanin, V. E. Chelnokov, A. N. Kuznetsov, M. G. Rastegaeva, E. I. Terukov, and M. P. Tsheglov, *Ohmic contacts to n-SiC-6H based on thin silicon carbide layers deposited by magnetron sputtering*, Fizika i Technika Poluprov (Aug. 1994).

2) A. N. Andreev and A. A. Lebedev, *Epitaxial-diffusion diodes in SiC-6H*, Pis 'ma v Zh. Techn. Fiz. (Dec. 1994).

3) A. N. Andreev, A. A. Lebedev and A. L. Syrkin, *Surface barrier height in*

metal-n-SiC-6H structures, Fizika i Technika Poluprov, (submitted in Dec. 1994).

4) A. N. Andreev, V. E. Chelnokov, A. M. Strel'chuk, N. S. Savkina and F. M. Snegov, *Investigation of 6H-SiC dinistor structure*, Fizika i Technika Poluprov (Nov. 1994).

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15) V. E. Chelnokov, A. M. Danishevsky, P. A. Ivanov, S. M. Starobinets and V. V. Zelenin, *Characterization of epitaxial silicon carbide films grown by chemical vapor deposition in the system* CH_3SiCl_3-H_2, Pis 'ma v Zh. Techn. Fiz. (Nov. 1994).

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2.2f **Invited papers presented at conferences.**

1) V. E. Chelnokov and Ivanov, *High Temperature 6H-SiC Devices Grown by Vacuum Sublimation Epitaxy*, Proc. of the 2nd HiTEC, ed. by D. B. King and F. V. Thome, p. XI-11, held in Charlotte NC, June 5-10, 1994.

2) V. E. Chelnokov, G. M. Gusinsky, V. K. Kudoyarova, E. I. Terukov and M. Tzolov, *IR-Spectroscopy, Raman and Elastic Recoil Detection Studies of a-C:H Films for Protection Coating*, presented at joint TATF94 and HVITF94,Dresden, Germany (March 1994)

3) V. E. Chelnokov, A. A. Lebedev, M. G. Rastegaeva, N. S. Savkina, A. M. Strel'chuk, A. L. Syrkin and S. Tyc, *Silicon Carbide Combined Transistor*, Proc. 2nd HiTEC, Charlotte, NC (June 1994).

4) A. Yu. Maksimov, A. A. Mal'tsev, S. G. Shulman and N. K. Yushin, *Ferroelectric Memory Cells based on SiC Structures*, Proc. 2nd HiTEC, ed. by D. B. King and F. V. Thome, p. P-153, Charlotte, NC (June 1994).

2.2g **Contributed papers presented at conferences. None at this time.**

2.3 *The Kurchatov Institute of Atomic Energy (Troitzk, Moscow Region): Yevgeny Velikhov, Director and Yu Baranov, Principal Investigator.*

2.3a **Key accomplishments.**

During this period a major goal of our work was to complete the set of experiments with plasmas initiated at the surface of a solid target in the presence of ambient gas. Both plasma in the gas itself and in the target vapors expanding in the gas were studied. The goal was to create and test against experimental evidences a reliable self-consistent model of plasma optics and fluid dynamics.

We assembled, calibrated and tested the modified experimental setup and ran first preliminary experiments with it. The modification of the diagnostic system was necessary to meet the requirements of new experiments on plasma expansion in vacuum.

1) The final experiments on dynamics of laser-supported detonation waves confirmed that the self-consistent model proposed for their description is absolutely adequate. All plasma properties (temperature and density distribution, transient absorption and refraction of the incident beam, plasma front propagation towards a laser source) predicted by the model are in a very good agreement with results of direct experimental measurements. Moreover,

gas dynamics outside of plasma plume (shocks propagating through the gas) is also correctly predicted by the model. It should be also noted that direct observation of shock waves in the gas around the plasma plume induced by microsecond pulses with power of 1 MW demonstrated very good repeatability of the shocks and their perfect cylindrical symmetry. Thus laser-supported detonation waves induced by the carbon dioxide laser pulses focused to the beam diameter of 100 microns are very convenient and inexpensive sources of cylindrical shock waves in gases with initial velocities 1 km/s (Mach number >3). These shock waves can be used in model experiments on supersonic flow dynamics.

Experiments on target plasma expansion through the gas were successfully completed by the series of experiments on Rayleigh-Taylor instability of expanding laser-induced plasmas. Our latest experiments included irradiation of "sandwich" targets consisting of the alternating layers of materials with different density and beam coupling coefficient. Changes of the thickness of each layer allowed us to control the spatial period of the initial plasma front perturbations. Streak camera imaging of expansion of these pre-perturbed plasmas made it possible to directly observe non-linear saturation of different spatial modes in the course of Rayleigh-Taylor instability.

2) The experiments mentioned above were the last steps in our program of studies of laser-induced plasmas created at a solid surface in a gas. The new program is mostly aimed at studies of target plasmas created in high vacuum. There are two reasons for these studies. From a scientific point of view, there is a missing step of the studies of expansion of laser-induced plasmas. All the studies reported in the literature since late 70s, were made using either lasers with pulse duration of several nanoseconds, or CW lasers. In the first case, the model of instant explosion of a compact plasma source proved to be valid. In

the second case, streams of slightly ionized target vapors were produced. However, microsecond pulses with intensity of about 100 MW/cm^2 can generate quasi-stationary streams of well ionized plasmas. Velocity of plasma expansion in this case is more than 50 km/s and therefore at the distances less than 5 cm we have a quasi-stationary plasma flow rather than a result of instant explosion. Interactions of such flows with each other and with a substrate has never been studied.

From a practical point of view, interaction of plasma and vapors flows expanding in vacuum with each other and with substrates is of serious interest because of growing number of applications for laser-assisted thin-film deposition. For many applications a uniform coatings should be deposited on a large areas (with diameter to several tens of cm). Low work function field emitters for flat panel displays are a good example. Deposition with multiple sources may an efficient solution, but the interaction between several plasma flows must be studied to understand how the characteristics of a resulting plasma flow depends on parameters of an individual source and the density of sources on a target.

To perform these experiments on target plasma mixing and interaction, we had to modify the vacuum system and diagnostics on our target chamber. A new target translation system can operate without deteriorating the vacuum on the level of 10^{-5} Torr.

The upgraded diagnostic system includes:

1) Electrostatic charge collector for time-of-flight measurements positioned at the distance of 90 cm from the target.
2) Grating monochromator with cooled CCD camera for spectrum recording in the range from 400 to 1000 nm.
3) Streak camera with image intensifier (temporal resolution 0.1 ns).
4) Low-noise PMT connected to digital storage oscilloscope.

Wide-aperture optics and monochromator together with high-gain liquid nitrogen

cooled CCD allowed us to record emission spectra from the plasma with density below 10^{13} cm^{-3} (in laser shots creating 5.10^{16} ions per shot).

RF discharge in a sealed cells filled with various rare gases was used as a source of reference spectra for system calibration. The range from 400 to 800 nm was used in our experiments, spectral resolution being 0.05 nm.

Spectra of C, Al, Pb were recorded and all lines important for diagnostic purposes identified in all the range of incident laser intensities where plasma was induced on the target. Molecules, neutral atoms, ions with ionization from +1 to +4 were detected.

Installation upgrade and all the necessary calibrations were completed by July 1994. Since then, a new set of experiments began. In the course of these experiments we measured parameters of plasma flows produced at the targets. A laser-induced plasma source has a duration of 3 microseconds and produces a jet of plasma with temperature from 3 to 5 eV and initial electron density 10^{17} cm^{-3}.

Collision of two laser-induced plasma jets with each other and collision of a plasma jet with a substrate were studied in different modes. Plasma density in a jet varies with distance R from the source as R^{-2}, thus changing R from 1 mm to several centimeters we could change the density in the collision area over several orders of magnitude (from 10^{16} to 10^{12}) and hence, the mode of plasma flows interaction ("fluid flow" or "collisionless penetration").

Formation of shocks in the "fluid flow" mode has been observed and studied in the course of preliminary experts. The results will be presented at Photonics West 95 Conference. They are listed below:

1) Angular profile of a plasma slow can be controlled by changing the shape of a laser spot on the target.

2) Recombination of the dense regions behind shocks goes all the way to formation of C2 molecules.

Experimental verification of self-consistent 2D model of laser-supported detonation

wave and associated plasma phenomena in the gas was completed.

It has been demonstrated that the model adequately describes both optical and gas dynamics effects including shock wave generation in the gas.

1) The diagnostic system has been upgraded and modified for experiments with laser-induced hypersonic plasma flows scheduled for late 1994 - 1995. All necessary calibrations and line identifications have been completed. Laser system upgrade in the progress so that by March 1995 we will be able to perform experiments using 1.06 and 0.53 micron pulses along with 10.6 micron pulses.

2) First experiments on collision of plasma flows with substrates and with each other have been made. Formation of the shock waves and dense plasma behind them was observed. It has been demonstrated for the first time that recombination in colliding carbon plasma flows results in efficient production of C2 molecules rather than other neutral species.

2.3b **Journal articles published.**

1) M. F. Kanevskii and M. A. Stepanova, *Multidimensional phenomena in laser produced plasma*, Proc. SPIE, 2119, p.92-103.

2) V. N. Anisimov, V. Yu Baranov, O. N. Derkach,V. A. Dolgov, M. F. Kanevsky, D. D. Malyuta, A. Yu Sebrant and M. A. Stepanova, *Experimental Studies of Optical Phenomena in a Laser-Induced Low-Temperature Plasma*, Proc. SPIE, 2119, p. 108-119.

3) V. Yu Baranov and A. Yu Sebrant, *Laser-induced plasma phenomena near a solid surface at the incident intensity in the range from 10 MW/cm^2 to 10 GW/cm^2*, AIP Conference Proceedings No. 318, p. 39-54.

4) O. N. Derkach, V. G. Grishina, F. F. Kanevskii and A. Yu Sebrant,

Instabilities of pulsed low-temperature laser-induced plasmas expanding in the low-density gas, AIP Conference Proceedings No. 318, p. 39-54.

2.3c **Journal articles accepted for publication. None at this time.**

2.3d **Journal articles submitted for publication. None at this time.**

2.3e **Journal articles currently in preparation. None at this time.**

2.3f **Invited papers presented at conferences. None at this time.**

2.3g **Contributed papers presented at conferences. None at this time.**

2.4 ***The Lebedev Physical-Technical Institute (Moscow): Igor Sobelman, Director and Igor Zhitnik, Principal Investigator.***

2.4a **Key accomplishments.**

Laboratory testing of the high resolution X-ray imaging optic and image detectors.

All optical elements for the Terek-C solar telescope and RES-C spectroheliograph were tested at the big vacuum testing installation "Ikar" with the laser plasma and X-ray tube sources.

Toroidal normal incidence mirrors (d = 30 mm, F = 800 mm) with Mo-Si coating for 175 A gave images of test-object illumination by short pulse laser plasma pulse with resolution of 0.25" which is close to the diffraction limit.

Crystal quartz spherical mirrors (D = 60 mm, F = 800 mm) were tested using X-ray tube on Al-K spectral line (8.34 A). A resolution of 80 micron (10") was obtained.

Holographic gratings (180 x 80 mm, 3600 1/mm) were tested for diffraction efficiency and scattered light. It was found that in the grazing incidence configuration (grazing angle ~ 2°) the efficiency reaches about 2.5% that is 2 times less than for ruled blased grating, but scattered light level for holographic grating is less than 1E-3 and 2 - 3 times less than for ruled grating.

Several types of image detectors had been designed for laboratory space applications. There are CCD-base intensified detectors with luminophore transformers (gadolinium oxisulfide) or with direct registration on bare Mcp plate of intensifier. The detectors have frame format 1024 x 1152 pixels and sensitivity 500 e/pix. Combined with amplification of image intensifier (one or two stage) it makes possible to register single X-ray photons in the 0.06 - 10 Kev range.

<u>In-flight testing of X-ray imaging optics and detectors of the TEREK-C telescope and RES-C spectroheliometer on-board the CORONAS-C orbital solar observatory (launched 2 March 94).</u>

The Terek-C telescope includes two XUV-channels with normal incidence multilayer mirrors: the MX channel (3 spherical mirrors for 132, 174, and 304 A, resolution up to 4") and HR channel (4 toroidal mirrors for 175 A, resolution up to 1",4 separate fields of view). The RES-C spectroheliograph includes 2 XUV spectral channels with objective holographic grating and normal incidence multilayer mirror (range 182 - 205 A, spectral resolution up to 0.02A, angular resolution up to 5"), two Mg XII channels with crystal quartz spherical mirrors (8.41 - 205 A, spectral resolution up to 4E - 4A, angular resolution up to 3") and FeXXV channel with spherical ring mirror (range 1.84 - 1.88 A, spectral resolution up to 8E - 5 A, spatial - up to 0.5'). The channels were equipped with intensified CCD-based detectors 1024 x 1152 pixels of two base types: with open MPC intensified and with luminophore screen transformers. During period from 10 March to 5 July 94 when high accuracy guiding system of the satellite was functioning, more than 200 observations with

each device were carried and more than 2000 images of the Sun were obtained in X-ray channels. All channels worked in accordance with preliminary predictions.

XUV-filters on base of SiC thin films.

It is proposed to use thin films of silicon carbide SiC as EUV bandpass filter transparent within 135 - 304 A band with excellent cutoff blocking of the strong solar L line radiation (1216 A). Mesh or porous membranes supporting 200 -800 A thickness free SiC filters have been made by RF sputtering. Such filters have 12 - 16% transparency in the 135 - 400 A range and less than 10E - 3 for H Lyman alfa. One sample of SiC filter was used in front of the MCP detector of the TEREK-C X-ray Telescope (on-board the CORONAS-I satellite).

We started manufacturing of optics and detectors for large solar imaging telescope SRT-C in frame of the next CORONAS mission (launch is planned to the end of 1995).

It includes aspherical (off-axis parabolouid) normal incidence X-ray mirror with diameter of 120 mm (which is 4 times more than we made earlier) which may provide angular resolution up to 0.5" and appropriate imaging detector. Mechanical design includes translation units with stepped motors for remote adjustment and precise pointing of separate optical channels. This work will be done in accordance with time schedule for overall scientific instrumentation preparation.

Development of hardware and software for image processing.

Special microprocessor electronic unit had been developed for the TEREK-C and RES-C instruments which include Intel 80C85 chip with RAM 4 - 8 Mbytes for device control, on-board processing and compression of the images. For CCD frame 1034 - 1152 pixels the readout time is 4 s, time for compression of images (2 x 2 or 4 x 4 pixels) - 10 - 13 s.

For the on-board computer software had been written on MSC-85 Assembler language. For on-ground tests of instruments and restoration of images from flight data a set of special programs was written on C++ language. It includes a program for repairing of data disturbed by the receiver noises, a program to extract service parameters and display images, a new program for image procession (background substraction, integration, zoom of selected areas, cutting on separate pictures, etc.).

The most important results of our work are:
A family of X-ray optics elements was created with principally new parameters. These elements were successfully tested on-board the CORONAS-I satellite (1994). Now it is the most representative collection of imaging X-ray optics flown into space.

It proved to be very successful to apply X-ray imaging methods and hardware in the field of detection of thermal neutrons. Here we succeed in creation of image detectors with record spatial resolutions (up to 30 micron) and development of neutron tomography. These works may have many industrial applications.

2.4b **Journal articles published.**

1) A. V. *Mitrofanov, F. A. Pudonin and I. A. Zhitnik,* SiC: filter for extreme ultraviolet, Proc. SPIE, v. 2280, p. 272-279 (1994).

2) I. Beigman and I. P. Tindo, *Luminescence X-ray polarimeters,* Proc. SPIE, v. 2265 (1994).

3) E. A. Andreev, E. N. Ragozin, V. A. Slemzin and I. A. Zhitnik, *Aspherical imaging multilayer mirrors with sub-arcsecond resolution for solar XUV-telescope,* Proc. SPIE, v. 2279 (1994).

4) A. P. Ignatiev, V. V. Krutov, S. V. Kuzin, M. M. Mitropolsky, A. A. Pertsov, E. N. Ragozin, N. N. Salashchenko, F. A. Sattarov, V. A. Slemzin, I. I. Sobelman, R. J. Thomas, I. P. Tindo and I. A. Zhitnik, *Testing and*

calibration of the optical elements for the XUV spectroheliograph under the CORONAS project, Proc. SPIE, v 2279 (1994).

2.4c **Journal articles accepted for publication.**

1) P. Y. Apel, A. Y. Diduk., T. I. Gromova, A. V. Mitrofanov and D. N. Tokarchuk, *Fabrication of metal microtubes using particle track membrane processing,* Proc. of the "17th international conference on Nuclear tracks in Solids," Dubna (1994,) (in press).

2) A. Isakov, V. Korneev, V. Krutov, S. Kusin, V. Mikerov, S. Oparin, A. Pertsov, E. Podolyak, I. Sobelman, I. Tindo, B. Tukarev and I. Zhitnik, *High resolution neutron tomography,* Physica Scripta (in press).

2.4d **Journal articles submitted for publication. None at this time.**

2.4e **Journal articles currently in preparation.**

1) E. Andreev, Yu Fotin, A. Ignatiev, V. Korneev, V. Krutov, S. Kuzin, V. Lomkova, A. Mitrofanov, S. Oparin, M. Pachomov, A. Pertsov, N. Salaschchenko, I. Sobelman, V. Slemzin, N. Soschin, V. Suchanov, V. Timofeev, I. Tindo and I. Zhitnik, *Instruments for the X-ray observation of the Sun in the 1.8 - 304 A region with the high spacial and spectral resolution (the Terec-C telescope and RES-C spectroheliometer),* Astronomical journal (Russian).

2) A. Ignatiev, V. Klepikov, V. Korneev, V. Krutov, S. Kuzin, V. Lomkova, A. Mitrofanov, S. Oparin, V. Oraevsky, A. Pertsov, V. Slemzin, I. Sobelman, A. Stepanov, I. Tindo and I. Zhitnik, *Data of X-ray observations of the Sun by means of telescope Terek-C and spectrometer RES-C on-board the CORONAS-I satellite* (March 10 - July 5, 1994) Astronomical Journal

(Russian).

3) A. Ignatiev,V. Ischkov, V. Korneev, V. Krutov, S. Kuzin, S. Kuznetsov, V. Lomkova, A. Mitrofanov, S. Oparin, A Pertsov, V. Rumin, V. Slemzin, I. Sobelman, I. Tindo and I. Zhitnik, *Dynamic of solar region MCM 7700 (April 1994) from X-ray 8.5 - 304 A and cosmic ray data obtained by the CORONAS-I satellite,* Letters to the Astronomical Journal (Russian).

4) A. Antonov, I. Grigorieva, S. Kusin, V. Krutov, V. Mikerov, V. Tukarev and I. Zhitnik, *Parabolic concentrators for thermal neutrons,* PTE.

2.4f **Invited papers presented at conferences.**

1) J. N. Fotin, A. P. Ignatiev, V. V. Korneev, V. V. Krutov, S. V. Kuzin, V. M. Lomkova, A. V. Mitrofanov, A. A. Pertsov, N. N. Salashchenko, V. A. Slemzin, I. I. Sobelman, V. V. Suchanov, I. P. Tindo and I. A. Zhitnik, *The TEREK-C telescope for imaging of the sun in the XUV range 13 - 30 nm on-board the CORONAS-I satellite,* Abstracts of the International Symposium "Applied Optics - 94," p 37, St. Petersburg, Russia (Nov. 1994).

2) J. N. Fotin, A. P. Ignatiev, V. V. Korneev, V. V. Krutov, S. V Kuzin, V. M. Lomkova, A. V. Mitrofanov, A. A. Pertsov, N. N. Salashchenko, F. A. Sattarov, V. A. Slemzin, I. I. Sobelman, V. F. Suchanov, I. P. Tindo and I. A. Zhitnik, *The "Res-K" imaging spectrometer for imaging of the Sun in extreme Uv range 18.5 - 20.4 nm, developed in frames of the "Coronas-I" project,* Abstracts of the International Symposium "Applied Optics - 94," p 37, St. Petersburg, Russia (Nov. 1994).

3) N. N. Kolachevsky, M. M. Mitropolsky, E. N. Ragozin, N. N. Salashchenko, V. A. Slemzin and I. A. Zhitnik, *Evaluation of imaging properties of soft-x-ray multilayer mirrors and their application to highly dispersive spectral imaging,* 4th International Colloquium on X-ray Lasers,

Book of Abstracts 4, p. 31, Williamsburg, Virginia (May 1994).

4) Yu Fotin, A. Ignatiev, V. Korneev, V. Krutov, S. Kuzin, V. Lomkova, A. Mitrofanov, S. Oparin, A. Pertsov, V. Slemzin, I. Sobelman, V. Suchanov, I. Tindo, A. Urnov and I. Zhitnik, *XUV observations of the Sun with the TEREC-C telescope and RES-C spectroheliometer on-board the Coronas-I observatory,* Part I, Report V. Oraevsky "Coronas-I" to the XXX COSPAR Meeting (July 1994).

5) V. Krutov, S. Kusin, V. Mikerov, P. Mudrik, T. Netushil, Z. Zavadil and I. Zhitnik,

On some parameters of radiological systems on the CCD base, Proc. of the "Defectoscopy - 93" meeting, Tabor (Sept. 1993).

2.4g **Contributed papers presented at conferences. (9)**

2.5 *Institute of Spectroscopy (Troitzk, Moscow Region): Yevgeny Vinogradov, Director and Vladilen Letokhov, Principal Investigator.*

2.5a Key Accomplishments:

In the field of *atomic physics and spectroscopy,* the proposal and study of *atomic optics* may be considered most important. Specifically, the possibility has been demonstrated of a deep focusing (down to a nanometer) of an atomic beam by the gradient force of laser radiation. This will make it possible in the future to develop an absolutely novel method of *nanolithography.* It has been shown to be possible to sort out atoms and trap ultracold atoms in the near field of laser radiation.

Significant results have been obtained in the field that may be referred to us the *laser-*

nuclear spectroscopy. First, the possibility has been demonstrated of the so-called partial population inversion on electronic-nuclear transitions, when the inversion results not from the inversion of the population of *nuclear levels*, but from the inversion of electronic transitions. The possibility has been examined of existing low-lying isomeric nuclear levels in multiply charged ions in a laser plasma. Secondly, the ultrasensitive laser resonance ionization spectroscopy (RIS) technique has been successfully used to study the characteristics of short-lived nuclei far from the β-stability band in real on-line experiments on an accelerator (in collaboration with CERN.) Thirdly, studies have been continued into the application of the RIS technique to the ultrasensitive analysis of trace elements, specifically platinum-group elements in kimberlites, as well as the development of laser method for detecting ultrarare long-lived radioactive isotopes.

In the field of laser spectroscopy of *molecules* using the method of IR laser multiple-photon excitation of vibrations in polyatomic molecules. An effect has been discovered of an abnormally rapid vibrational relaxation upon collisions.

In the field of the laser spectroscopy of *surface*, the possibility has been demonstrated for the first time of the implementation of photoelectron laser projection spectromicroscopy with a subwavelength spatial resolution. Even in the very first experiments, it has proved possible to achieve a magnification of the order of $3 \cdot 10^4$ and a spatial resolution of some 60nm. The new method has been shown to possess a chemical (spectral) selectivity. Thus, it has for the first time proved possible to achieve a spectral resolution simultaneously with a subwavelength spatial resolution. In addition, a new method has been suggested for conducting nanolocal chemical reactions on surface and the possibility considered of effecting the selective absorption of molecules on surface.

In the field of laser spectroscopy of *condensed media*, research has been centered on the use of a *femtosecond* time resolution to study ultrafast electronic excitation relaxation processes in new materials: high-temperature superconductors, fullerites and polydiacetylene. The mechanism has been explained of the photodarkening of fullerite films

under the effect of high-power femtosecond laser pulses. Besides, studies have been completed into the mechanism of ablation of absorbing media by nanosecond laser pulses. The significant role has been revealed of the spatially nonuniform deposition of laser energy. This effect reduces the laser ablation threshold by approximately an order of magnitude. This is important for biomedical laser ablation applications, for biotissue is essentially inhomogeneous medium. Finally, ways have been found to develop a novel technique of *optical tomography* based on the use of ultrasonic waves generated by laser pulses.

All the research results have either already been published or present to print, and almost all of the results have been reported at international conferences (see appendix.)

Participating in the above research work has been around 30 scientists and engineers (full-time equivalent,) who have been supported financially by the DOD. During the period under review, some $40,000 has been spent on salaries and wages, i.e., the cost of one publication in an international magazine has amounted to some $1,000(!).

2.5b **Journal articles published.**

1) V. V. Klimov and V. S. Letokhov, *A simple theory of the near field in diffraction by a round aperture*, Opt. Comm. 106 (1994) p. 151-154.

2) V. I. Balykin, V. V. Klimov and V. S. Letokhov, *Tight focusing of an atomic beam by the near field of diffracted laser light*, Amer. Inst. of Phys. (1994) p.235-239.

3) V. I. Balykin, V. V. Klimov and V. S. Letokhov, *Laser near field lens for atoms*, J. Phys. II France 4 (1994) p. 1981-1997.

4) V. V. Klimov and V. S. Letokhov, *Selection of particles by a gradient force in the near field of laser light*, Amer. Inst. of Phys. (1994) p. 608-611.

5) V. V. Klimov and V. S. Letokhov, *Selective sorting of neutral atoms and molecules by the gradient dipole force in the near field of laser radiation*, Opt. Comm. 110 (1994) p. 87-93.

6) R. Grimm, V. S. Letokhov, Y. B. Ovchinnikov and A. I. Sidorov, *Resonant light pressure on atoms in a bichromatic standing wave*, Opt. and Spectroscopy 76, No.2 (1994) p. 188-197.

7) S. Akhmanov, *Frontiers in nonlinear optics,* Inst. of Phys., memorial vol.

8) V. I. Balykin, V. S. Letokhov and Y. B. Ovchinnikov, *Channelling of atoms in a standing laser light wave.*

9) V. S. Letokhov, *Partial population inversion for electron-nuclear transitions in multiply charged ions*, Opt. Comm. 106 (1994) p. 227-230.

10) G. S. Hurst and V. S. Letokhov, *Resonance ionization spectroscopy*, Amer. Inst. of Phys. (Oct. 1994) p. 38.

11) P. V. Duppen, V. N. Fedoseyev, G. Huber, Y. Jading, O. C. Jonsson, R. Kirchner, K. L. Kratz, M. Rrieg, E. Kugler, J. Lettry, T. Mehren, V. I. Mishin, T. Rauscher, H. L. Ravn, F. Scheerer, O. Tengblad, A. Wöhr and the ISOLDE Collaboration, *Study of short-lived silver isotopes with a laser ion source*, 7th Intern. Symp. (RIS-1994).

12) J. Dobaczewski, V. N. Fedoseyev, Y. Jading, K. L. Kratz, V. I. Mishin, P. Möller, B. Pfeiffer, H. L. Ravin, F. Scheerer, F. K. Thielemann, W. B. Walters, A. Wöhr and the Isolde Collaboration, *Nuclear model predictions near the neutron drip line relevant to r-process nucleosynthesis*, Proc. of Tours Symp. on Nuclear Phys., Tours, France (1994). .

13) S. A. Aseev, Y. A. Kudryavtsev, V. S. Letokhov and V. V. Petrunin, *Laser collinear ionization of accelerated atoms in a beam as a method for detecting rare isotopes of krypton*, Optics and Spectroscopy, Vol. 76, No. 2, (1994) p. 203-211.

14) V. S. Letokhov and E. V. Moskovets, *Cat's-eye reflectron*, Appl. Phys. B 59, (1994) p. 547-552.

15) V. S. Letokhov, *Multiple photon laser photochemistry*, Chinese Jour. of

Lasers, Vol. B3, No. 4, (Aug. 1994).

16) C. M. Barshick, R. N. Compton, A. V. Dem'yanenko, R. E. Haufler, R. L. Hettich, Changming J. , A. A. Puretzky and A. A. Tuinman, *Synthesis and characterization of molybdenum carbide clusters* $Mo_n \ C_{4n}$ *(n = 1 to 4),* Science, Vol. 263, (Jan. 1994).

17) P. I. Ionov, A. A. Kosterev, A. L. Malinovsky and E. A. Ryabov, *Vibrational exchange in the manifold of high-frequency vibrations of the* CH_2F_2 molecule, Chem. Phys., 178 (1993) p. 363-370.

18) M. V. Ashikhmin, Y. B. Belyaev, A. V. Dem'yanenko, V. S. Letokhov and E. A. Ryabov, *Laser [2+1] REMPI detection of Br atoms in unimolecular decomposition reactions*, Chemical Phys., 227 (1994) p. 343-348.

19) V. B. Laptev, E. A. Ryabov, *Dissociation of siloxane chain by pulsed radiation of CO laser*, Chem. Phys.(Russian) Vol. 13, No. 1 (1994) p. 37.

20) Y. E. Belyaev, A. V. Dem'yanenko, E. V. Moskovets and A. A. Puretsky, *Distinctive behavior of vibrational distribution of* MO_2*, which appears at ultra violet excitation of* $MO(CO)_6$ *in gaseous phase*, Chem. Phys. (Russian) Vol. 13, No. 2 (1994) p. 82.

21) A. Golov and S. Sekatskii, *Rydberg branch of electronic excitations of helium clusters*, Physica B 194-196 (1994) p. 555-556.

22) V. N. Konopskii, V. S. Letokhov and S. K. Sekatskii, *Study of LiF:*F_2^- *- Crystal surface with subwavelength spatial resolution*, Pis'ma ZLETF, 60 (1994) p. 691-693.

23)V. S. Letokhov and S. K. Sekatskii, *Laser resonant photoionization of absorbing centers at a surface*, Optics and Spectroscopy, Vol. 76, No. 2, (1994) p. 271-277.

24) T. T. Basiev, V. S. Letokhov, S. K. Sekatskii and V. V. Ter-Mikirtychev, *Laser resonance external photoelectric effect in* F_2^- *color centers of LiF*

crystals, Appl. Phys. A58, (1994) p. 467-470.

25) V. S. Letokhov, Y. E. Lozovik, S. P. Merkulova and S. K. Sekatskii, *The possibility of nanolocal reactions on surfaces*, Phys. Ltrs. A, 189 (1994) p. 131-133.

26) S. V. Chekalin, A. L. Dobryakov, V. M. Farztdinov, V. V. Golovlev, V. S. Letokhov, Y. E. Lozovik, Y. A. Matveets and A. G. Stepanov, *Femtosecond spectroscopy of Yba2Cu3O$_{7-\delta}$ superconductors. Measurement of the electron-phonon coupling parameter and observation of the superconducting gap,* Optics and Spectroscopy, Vol. 76, No. 6, (1994) p. 871-879.

27) V. M. Farztdinov, V. S. Letokhov, Y. E. Lozovik, Y. A. Matveets and A. G. Stepanov, *Femtosecond dynamics of photoinduced darkening in C_{60} films,* J. Phys. Chem. 98, (1994) p. 3290-3294.

28) I. V. Bezel', S. V. Chekalin, Y. A. Matveets, A. G. Stepanov and A. P. *Yartsev, Two-photon absorption of an intense femtosecond pulse in glasses doped with microscopic semiconductor crystals at a photon energy greater than the band gap*, Amer. Inst. of Phys., (1994) p. 403-407.

29) I. V. Bezel', S. V. Chekalin, V. S. Letokhov, Y. A. Matveets, A. G. Stepanov and A. P. Yartsev, *Two-photon absorption of powerful femtosecond pulses in C_{60} film*, Chem. Phys. Lett. 218 (1194) p. 475-478.

30) V. M. Farztdinov, V. S. Letokhov and Y. E. Lozovik, *Saturation of the fullerite photodarkening at high laser energy fluences*, Chem. Phys. Lett. 224, (1994) p. 493-500.

31) R. O. Esenaliev, A. A. Karabutov, V. S. Letokhov, T. V. Malinsky and A. A. Oraevsky, *Studies of acoustical and shock waves in the pulsed laser ablation of biotissue*, Laser in Surg. and Medic. 13 (1993) p. 470-484.

32) V. V. Golovlyov, V. S. Letokhov, Laser ablation of absorbing liquids, Appl. Phys. B 57, (1993) p. 417-423.

33) R. O. Esenaliev, V. V. Golovlyov and V. S. Letokhov, *Ablation of an optically homogeneous absorbing medium by scattered pulsed laser radiation,* Appl. Phys.B 57 (1993) p. 451-457.

34) R. O. Esenaliev, A. A. Karabutov, V. S. Letokhov and N. B. Podymova, *Laser ablation of aqueous solutions with spatially homogeneous and heterogeneous absorption,* Appl. Phys. B 59, (1994) p. 73-81.

35) T. Karu and V. S. Letokhov, *Possible benefits of two-quantum excitation in ALA-PDT?,* J. Photochem. Photobiol. B: Biol. 23, (1994) p. 261-262.

36) R. Esenaliev, T. Karu, V. S. Letokhov and O. Tiphlova, *Two different mechanism of low-intensity laser photobiological effects on Escherichia Coli,* J. Photochem. Photobiol. B: Biol. 24 (1994) p. 155-161.

2.5c **Journal articles accepted for publication.**

1) V. I. Balykin and V. S. Letokhov, *Atom optics with laser light,* Vol. in series, Laser Science and Technology (in press).

2) R. Grimm, Y. B. Ovchinnikov and J. Söding, *A coherent beam splitter for atoms based on a bichromatic standing light wave,* Version of Dec. 1993, Opt. Lett. (in press).

3) V. A. Alekseev, D. D. Krylova and V. S. Letokhov, *Sympathetic cooling of two trapped ions,* Phys. Scripts (in press).

4) V. S. Letokhov, M. A. Ol'Shaniî and Y. B. Ovchinnikov, *Laser cooling of atoms:* A Review, Quantum Optics (in press).

5) V. S. Letokhov, *Impact of laser and nuclear technologies,* Proced. of Symp. "Innov. Laser Tech. in Nuclear Energy," Japan (in press).

6) Y. A. Kudryavtsev and V. S. Letokhov, *Laser detection of rare isotopes,* Vol. in series, "Laser Science and Technology" (in press).

7) S. A. Aseyev, Y. A. Kudryavtsev, D. V. Laryushin, V. S. Letokhov and V. V. Petrunin, *New field ionizer for fast Rydberg atoms*, "7th International Symposium on Resonance Ionization Spectroscopy and Its Applications" (RIS-94) Germany, Proced. (in press) .

8) S. A. Aseyev, Y. A. Kudryavtsev and V. V. Petrunin, *Ionization of fast Rydberg atoms in longitudinal and transverse electric fields*, "7th International Symposium on Resonance Ionization Spectroscopy and Its Applications" (RIS-94) Germany, Proced. (in press) .

9) S. A. Aseyev, Y. A. Kudryavtsev, V. S. Letokhov and V. V. Petrunin, *Detailed study of collisional background in the collinear laser photoionization of fast atoms*, "7th International Symposium on Resonance Ionization Spectroscopy and Its Applications" (RIS-94) Germany, Proced. (in press) .

10) F. Albus, V. N. Fedoseyev, R. Grzywacz, M. Huyse, Z. Janas, H. Keller, R. Kirchner, O. Klepper, H.-J. Kluge, V. I. Mishin, G. Passler, A. Piechaczek, A. Plochocki, E. Roeckl, K. Rykaczewski, F. Scheerer, K. Schmidt, J. Schwarzenberg, J. Szerypo, P. Van Duppen, L. Vermeeren, J. Zylicz, *Beta decay of the new isotope ^{101} Sn*, "7th International Symposium on Resonance Ionization Spectroscopy and Its Applications" (RIS-94) Germany, Proced. (in press) .

11) F. Albus, V. N. Fedoseyev, R. Kirchner, O. Klepper, H.-J. Kluge, V. I. Mishin, G. Passler, E. Roeckl, F. Scheerer, K. Schmidt and N. Trautmann, *Study of short-lived tin isotopes with a laser ion surface*, "7th International Symposium on Resonance Ionization Spectroscopy and Its Applications" (RIS-94) Germany, Proced. (in press).

12) V. S. Letokhov and E. A. Yukon, *Excitation of isomeric low-lying levels of heavy nuclei and laser plasma*, Laser Phys. (in press).

13) V. S. Letokhov, *Toward laser control of molecular motion*, Proceed. of Symposium "Molecular Spectroscopy and Molecular Dynamic", Germany (in press).

14) V. S. Letokhov, Y. E. Lozovik and A. M. Popov, *Possibility of selective absorption of molecules on a modified surface*, Journ. of Phys. Chem. (in press).

15) V. S. Letokhov, *Towards site-selective laser IR MPE/D on noncompact polyatomics*, Proceed. of Symposium "Femtosecond Infrared Multiphoton Dissociation" Germany (in press).

16) V. S. Letokhov, *Multiphoton photochemistry and photobiochemistry with ultrashort laser pulses*, Chapter in book "Ultrafast Processes in Chemistry and photobiology" (in press).

17) A. A. Karabutov, V. S. Letokhov and N. B. Podymova, Letter: *Time-resolved optoacoustic detection of absorbing particles in scattering media*, Journ. of Mod. Opt., Vol. 00, No. 0, (1994)p. 17 (in press).

18) A. A. Karabutov, V. S. Letokhov and N. B. Podymova, *Time-resolved optoacoustic measurement of absorption of light by nonhomogeneous media*, Appl. Opt. (in press).

19) R. O. Esenaliev, O. A. Golovlyova, V. V. Golovlyov and V. S. Letokhov, *Effect on erytrocytes of acoustic waves generated upon absorption of laser radiation*, "Lasers in the Life Sciences" (in press).

2.5d **Journal articles submitted for publication.**

1) V. V. Klimov, V. S. Letokhov and Laboratoire de Physique des Lasers, *Laser-near-field-based atomic lens: Quantum wave optics consideration* (submitted to J. Modern Opt.)

2) V. V. Klimov, V. S. Letokhov and Laboratoire de Physique des Lasers, *New atom trap configuration in the near field of laser radiation* (submitted to Phys. Rev. Lett.)

3) G. I. Bekov, V. M. Gulevich, I. P. Ilupin, A. N. Kursky, V. S. Letokhov, D. Y. Pakhomov and S. M. Sablukov, *Ruthenium, rhodium and iridium in the kimberlites and plutonic nodules from the Kimberlite Pipes of Russia,* (submitted to Geochimica Acta.)

2.5e **Journal articles currently in preparation.**

1) V. V. Klimov and V. S. Letokhov, *Selection of atoms by laser gradient force.*

2) V. S. Letokhov, *Laser Maxwell's demon.*

3) V. V. Klimov and V. S. Letokhov, *Line width of atom inside of spherical dielectric drop or cavity.*

4) V. N. Fedoseyev, G. Huber, Y. Jading, O. C. Jonsson, K.-L. Kratz, E. Kugler, V. I. Mishin, H. L. Ravn, O. Tengblad, P. Van Duppen, A. Wöhr and ISOLDE Collaboration, *Laser ion source for on-line production of unstable nickel isotopes.*

5) S. A. Aseyev, Y. A. Kudryavtsev, D. V. Laryushin, V. S. Letokhov and V. V. Petrunin, *Ionization of fast Rydberg atoms by a magnetic field.*

6) S. A. Aseyev, Y. A. Kudryavtsev, V. S. Letokhov and V. V. Petrunin, *Laser resonance photoionization spectroscopy of fast atoms in the beam.*

7) V. M. Gulevich, V. S. Letokhov, D. Y. Pakhomov and A. D. Zuzikov, *Optimum schemes for resonance photoionization of the lead atom.*

8) V. M. Gulevich, V. S. Letokhov, D. Y. Pakhomov and A. D. Zuzikov, *Optimum schemes for resonance photoionization of the cadmium atom.*

9) M. V. Ashikhmin, Y. E. Belyaev, A. V. Dem'yanenko, V. S. Letokhov and E. A Ryabov, *Study of unimolecular IR multiphoton dissociation of $(CF_3)_3$ CBr molecule un molecular beam using [2 + 1] REMPI detection of Br atoms.*

10) A. A. Kosterev, A. A. Makarov, A. L. Malinovsky and E. A. Ryabov, *Collision-induced intramolecular vibrational relaxation.*

11) V. S. Letokhov, Y. A. Matveyets and A. G. Stepanov, *The nonlinear transmission by a C_{00} film of femtosecond pulses central wavelength of 503 and 570 nm.*

12) N. I. Afanasyeva, V. S. Letokhov, Y. A. Matveyets, A. N. Shchegolikhin and A. G. Stepanov, *Nonlinear optical properties of polyacetylene and polydiacetylene in the intensity range 10^8 -10^{11} W/cm^2.*

2.5f **Invited talks at International and Symposium Conferences.**

1) V. S. Letokhov, *Laser light control of the molecular motion,* Invited talk at Intern. Conf. "Molecular Spectroscopy and Molecular Dynamics," (Aug./Sept. 1994) Germany.

2) V. S. Letokhov, *Impact of laser and nuclear sciences and technologies,* Plenary lecture at Intern. Symp. "Laser Technology for Nuclear Technology," (March 1994) Tokyo.

3) V. G. Minogin, *Coherent states of atoms in laser field* Invited talk at Intern. Conf. "Quantum Optics of Atoms and Molecules," (Feb. 1994) Helsinki.

4) V. I. Balykin, *Laser near field lens for atoms,* Intern. Symp. "Optics and Interferometry with atoms," (June 1994) France.

5) V. V. Klimov and V. S. Letokhov, *Atom traps in near field of laser radiation,* Intern. Symp. "Optics and Interferometry with Atoms," (June 1994) France.

6) V. I. Michin, *Laser ion source for on-line isotope separation,* Invited talk at "7th Intern. Symp. on Resonance Ionization Spectroscopy and its Applications" (RIS-94), (July 1994) Germany.

7) V. M. Farztdinov, *Femtosecond optical spectroscopy of high T_c superconductors and fullerites,* Adriatico Intern. Research Conf. "Ultrafast Phenomena and Applications," ICTP, (Dec. 1994) Italy.

8) N. I. Afanasyeva, V. G. Artijushenko, A. A. Lerman and V. S. Letokhov, *Spectral biodiagnostics of polymer implants, biomaterials and tissues,* "Book of Abstracts," ESOPS-11, (1994) Spain.

2.5g **Contributed papers at International Conferences.**

1) J. Dobaczewsky, V. N. Fedoseyev, K. -L. Kratz, V. I. Mishin, P. Moller, B. Pfeiffer, H. L. Ravn, F. Scheerer, F. -K. Thielemann, W. B. Walters, A. Wöhr and ISOLDE Collaboration, *Nuclear model predictions near the neutron drip line relevant to r- process nucleosynthesis,* (oral presentation) Tours International Symp. "Nuclear Physics II," (Aug./Sept. 1994) France.

2) F. Albus, V. N. Fedoseyev, R. Kirchner, O. Klepper, H.-J. Kluge, V. I. Mishin, G. Passler, E. Roeckl, F. Scheerer, K. Schmidt and N. Trautmann, *Study of short-lived tin isotopes with a laser ion source,* (poster presentation) 7th Intern. Symp. "Resonance Ionization Spectroscopy and its Applications," (RIS-94), (July 1994) Germany.

3) V. N. Fedoseyev, G. Huber, Y. Jadin, O. C. Jonsson, R. Kirchner, K. -L. Krantz, M. Krieg, E. Kugler, J. Lryyty, Y. Mehren, V. I. Mishin, T. Rauscher, H. L. Ravn, F. Scheerer, O. Tengblad, P. Van Duppen, A. Wöhr and ISOLDE Collaboration, *Study of short-lived silver isotopes with a laser ion source,* (poster presentation) "7th Intern. Symp. on Resonance Ionization Spectroscopy and its Applications" (RIS-94) (July 1994) Germany.

4) R. Grimm, Y. B. Ovchinnikov and J. Söding, *Atom strahlteilung durch bichromatisches Licht,* "Deutsche Pyhsikalische Gesellschaft," Talk (March 1994) Germany.

5) P. Bouyer, A. Fioretti, R. Grimm, Y. B. Ovchinnikov, C. Salomon, J. Söding and M. Zielonkowski, *Die stimulierte bichromatische kraft: Atom - strahlabbremsung auf kürzester distanz.*

7th International Symposium on Resonance Ionization Spectroscopy and its Applications (RIS-94)

6) S. A. Aseyev, Y. A. Kudryavtsev, V. S. Letokhov, V. V. Petrunin and D. V. Zaryushin, *A new field ionizer for fast Rydberg atoms* (oral).

7) S. A. Aseyev, Y. A. Kudryavtsev and V. V. Petrunin, *Ionization of fast Rydberg atoms in longitudinal and transverse electric fields* (poster).

8) S. A. Aseyev, Y. A. Kudryavtsev, V. S. Letokhov and V. V. Petrunin, *Detailed study of collisional background in the collinear laser photoionization of fast atoms.*

European Group for Atomic Spectroscopies 26th E.G.A.S. Conference, Barcelona (July 1994).

9) S. A. Aseyev and V. V. Petrunin, *Ionization of fast Rydberg atom in magnetic field as new approach to the study of atomic behavior in crossed fields* (oral).

10) S. A. Aseyev, Y. A. Kudryavtsev, V. S. Letokhov and V. V. Petrunin, *Detailed study of collisional background in the collinear laser atomic photoionization spectroscopy* (poster).

11) R. Grimm, Y. B. Ovcninnikov and J. Söding, Magneto-optical byprism for atom holography and interferometry, (poster) Quantum Optics, Switzerland (Sept. 1994).

Fourteenth International Conference on Atomic Physics, (ISAP-1994) University of Colorado Boulder, Colorado, (July/Aug. 1994).

12) S. A. Aseyev, V. V. Petrunin, *Ionization of fast Rydberg atoms by a magnetic field* (poster).

13) S. A. Aseyev, V. V. Petrunin, *Description of Rydberg atom ionization in permanent magnetic field in terms of transnational motion* (poster).

14) A. A. Kosterev, A. L. Malinovsky, E. A. Ryabov and S. A. Tretyak, *Ultrafast collisional redistribution of vibrational energy in highly excited polyatomic molecules,* Intern. Conf. "Molecular Spectroscopy and Molecular Dynamics, Theory and experiment,"Germany (Aug./Sept. 1994).

15) A. A. Kosterev, A. L. Malinovsky and E. A. Ryabov, *Ultrafast collisional redistribution of vibrational energy in small polyatomic molecules,* "2nd European Congress on Molecular Spectroscopy,"Germany (Sept. 1994).

16) E. Akesson, S. V. Chekalin, V. M. Farztdinov, T. Gillbro, Y. A. Matveets and V. Sündström, *Ultrafast processes in fullerenes and fullerites,* (poster) EUCHEM European Conference "Ultrafast Processes in Chemistry and Biology," Sweden (June 1994).

17) N. I. Afanasyeva, Y. E. Lozovik, Y. A. Matveets, S. P. Merkulova and A. N. Shcegolikhin, *IR-spectroscopy of nanotubes,* (talk) Intern. Conf. "Spectroscopy Across the Spectrum," England, UK (July 1994).

18) N. Afanasyeva, V. Artiyshenko, A. Lerman and V. Plotnichenko, *Molecular spectroscopy with fiber optics for biodiagnostics of tissues,* "Book of Abstracts of XX Intern. Congress on Molecular Spectroscopy," Germany (Sept. 1994).

19) N. Afanasyeva, V. Vasiljev and K. Vorotilov, *Structure, properties and applications of ormosils films,* "Book of Abstracts of MRS-94," p. 47, Boston, Massachusetts (Fall meeting, 1994).

20) *Vibrational spectroscopy in biodiagnostics of polymer implants and tissues,* "Book of Abstracts of SSIR-94," p. 9, Norway (June 1994).

21) N. Afanasyeva, V. Artiyshenko, A. Lerman, *Spectral biodiagnostic of imports and tissues,* "Book of Abstracts of Conf. Spectroscopy across the spectrum" Norwich, University of East England (July 1994).